# A Liquid Crystal Based Contact Lens Display Using PEDOT: PSS and Obliquely Evaporated SiO2

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## Abstract

*An active spherically conformed liquid crystal cell is presented comprising PEDOT:PSS as a transparent conductive layer and obliquely evaporated SiO2 as an alignment layer. To tackle compatibility issues with the SU8 processing needed for the spacers, an additional buffer layer was included in the fabrication process. The electro-optic response is inspected closely and a contrast measurement is given.*

## Author Keywords

contact lens; flexible display; guest-host; liquid crystal cell

## 1. Background and Objectives

When seeking to further integrate mobile displays in our daily routine one should strive for benefits such as a hands-free, instant access to our display, a lightweight and almost unnoticeable device and even a display providing a superimposed view onto our real view of the world. Although some of these benefits are being realized by head-up displays, even the most modern implementations require goggles that are significantly heavier than common glasses. Moreover, most people are reluctant to wear glasses went they normally do not need them, which is also one of the reasons why 3D TV is being adopted slowly One possible way of overcoming these hurdles is bringing the display even closer to the eye and integrate it into a contact lens. Such a contact lens display aims for a bigger coalescence of the man-machine border and could serve as an enhancement of the real view, rather than feeling as just an add-on. Of course, there are many technological challenges in realizing a contact lens display. Aside from power management, focusing issues and biocompatibility requirements, the main question arises, however, which display technology would be best suited for integration into a contact lens. A considerable amount of research has been performed by the group of B. Parviz into the integration and powering of micro-LEDs into a contact lens [1-2]. Although a single-pixel wireless contact lens display has been demonstrated, the emissive nature of the technology might hamper the development of a high resolution display due to its considerable power consumption. Alternatively, one can incorporate an electro-optic element capable of modulating incoming light, rather than emitting new light, thus possibly reducing the required power. Although there is a variety of electro-optic effects capable of modulating the incoming light (e.g. electrowetting, electrochromic, electrophoretic etc…), we investigated a liquid crystal based technology due to its low voltage and power consumption. Since a contact lens is, however, often not thicker than 120 μm, a polarizer free approach is needed as no sufficiently thin polarizers are commercially available at present. Therefore, a transmissive guest-host configuration as proposed by White and Taylor [3] was chosen with a homeotropic alignment and a twist angle of 180°. A conceptual drawing of how such a liquid crystal (LC) based contact lens display may look like is presented in Figure 1. The central part of the contact lens display comprises a spherically shaped LC cell, filled with the guest-host liquid crystal mixture. Previously, we reported on the mechanical design and the specific processing issues which arise during the fabrication of such a spherically conformed LC cell [4]. In this work, however, the focus is turned to the achievement of the electro-optic response, with in particular the alignment of the liquid crystal molecules inside the LC cell and the integration of the transparent conductive layer.

## 2. Methods

***Design of the LC cell:*** As mentioned above, we have previously studied the design of the LC cell itself. This resulted in an LC cell made of two polyethylene terephthalate (PET, a cheap and flexible polymer that can be easily molded at low temperatures) films glued together with a circular glue joint but with a patterned permanent SU8 photoresist layer in between (see Figure 2). This patterned SU8 layer comprises an interlaced finger structure as an entrance for filling of the LC cell, a barrier to control the glue flow towards the centre of the cell and a matrix of cylindrical spacers (r = 10 μm) placed with a 200 μm pitch. After the circular LC cells are cut out with a $CO_2$-laser, they are molded into a spherical shape using a mold with a radius of 7.8 mm, a standard radius used in contact lenses [5]. To reduce the total thickness of the cell, the thickness of the PET film at the convex side was set at 50 μm, while the PET film at the concave side was

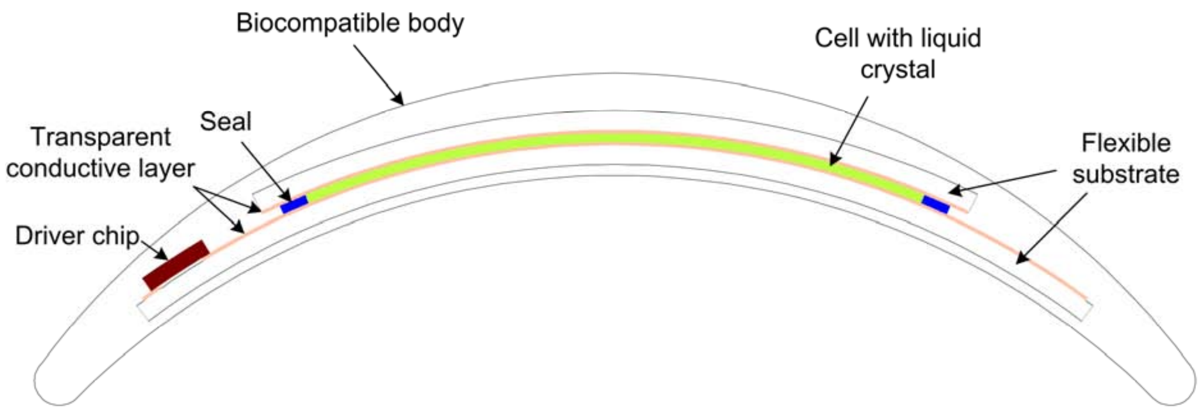


**Figure 1.** Conceptual drawing of the contact lens display.

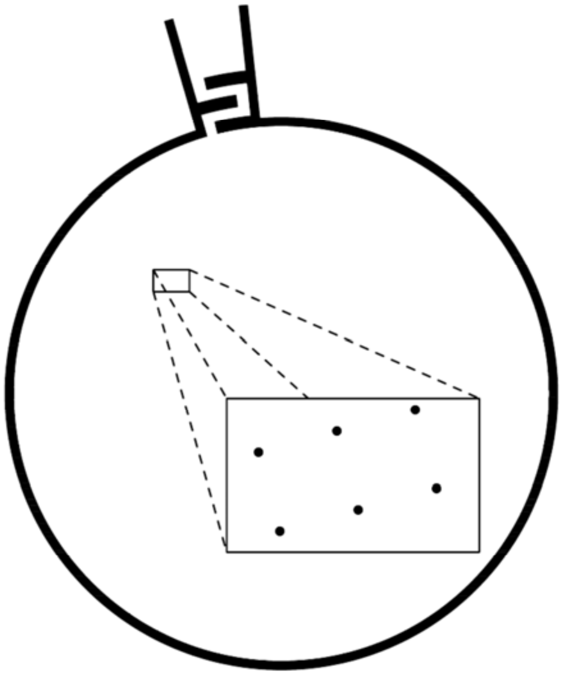

**Figure 2.** Mask pattern of our photolithographic layer. It comprises a circular area filled with a matrix of vertical cylinders, a barrier to control the glue flow and an interlaced finger structure to reinforce the entrance of the LC cell.

fixed at 75 µm.

***Material Choice and Compatibility Issues:*** In order to actively switch our LC cell, a transparent conductive layer and an alignment layer are needed. Although Indium Tin Oxide is the standard transparent conductive material for most LCD's, ITO layers in early prototypes always cracked during the molding step. Notwithstanding the LC cell could still be switched, the long term reliability can be assumed to be small in such a configuration, especially since additional stresses introduced during handling of the cell could further crack the ITO layer and permanently destroy conductive paths. We therefore chose poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) as an alternative, being a conductive polymer with a proven flexibility [6]. For the alignment of the LC molecules, we selected obliquely evaporated $SiO_2$, providing a robust alignment layer which requires only a low temperature deposition step, thereby reducing the risk of introducing undesired thermal stresses in the underlying PET film. However, the integration of both the PEDOT:PSS and the obliquely evaporated $SiO_2$ into the fabrication of the LC cell with its permanent SU8 layer showed compatibility issues. Firstly, directly processing SU8 on top of PEDOT seemed impossible as for unknown reasons the unexposed SU8 areas could not be fully etched away with normal or prolonged developing times. As can be seen in Figure 3, an optical profilometer scan reveals an uneven, residual layer of several microns thick being still present on top of the PEDOT. Secondly, direct evaporation of the $SiO_2$ onto PEDOT sometimes resulted in poor alignment performance, thus also eliminating the use of this layer as a buffer between PEDOT and SU8. Moreover, the different processing steps of SU8 onto the obliquely evaporated $SiO_2$ would also likely influence the quality of the alignment. To tackle these problems, an additional layer of vertically evaporated $SiO_2$ was deposited onto the PEDOT, serving as a buffer for the subsequent SU8 processing. Afterwards, the alignment layer way deposited directly onto the SU8 spacers and the exposed buffer layer.

***Fabrication Process:*** The fabrication process is can now be fully described and starts with the lamination of cleaned PET films (50 and 75 µm) onto a glass carrier using a temporary adhesive (see Figure 4). After a plasma treatment to improve adhesion, PEDOT:PSS (Orgacon S305) was spincoated on top of the PET films and a 50 nm thick buffer layer of vertically evaporated $SiO_2$ was applied onto the PEDOT. A 10 µm thick photoresist (SU8 3010) was spin coated and patterned on top of the 75 µm PET film, bearing the features as mentioned above. Both PET films then received the alignment layer by obliquely evaporating $SiO_2$. A flexible glue (UVS 91) was deposited just next to the SU8 barrier with an automatic dispenser, creating a circular glue joint with a small interruption at the interlaced finger structure. Afterwards, the 50 µm PET film was put on top and the total stack was then pressed together, ensuring a close contact as the stack was subsequently illuminated with UV light to cure the glue joint. After curing, the glass carriers were removed and the LC cells were cut out through the glue joint with a $CO_2$-laser. Additional rectangular contact areas were provided at the side of the LC cell which, after fabrication, were connected to a power source with a copper tape. Due to the thermal ablation mechanism of the $CO_2$-laser, the opening of the LC cell was inadvertently closed in most of the samples and needed reopening. An excimer laser was accordingly set to ablate material away at the edge of the contact lens, going through the first PET film but stopping 10

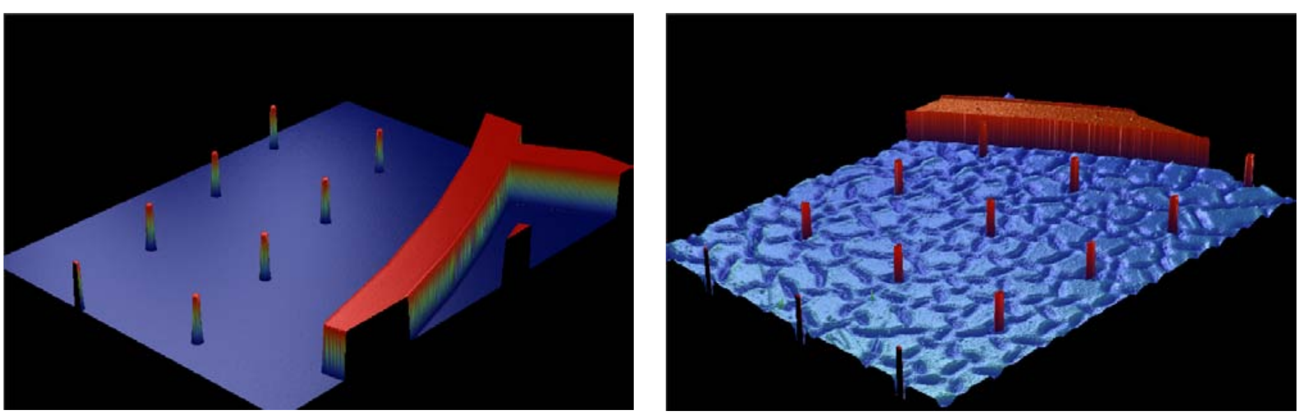

**Figure 3.** Left: SU8 processed on top of glass, showing good feature sizes. Right: SU8 processed on PEDOT:PSS with the same developing time reveals an uneven, residual layer of several microns thick still being present.

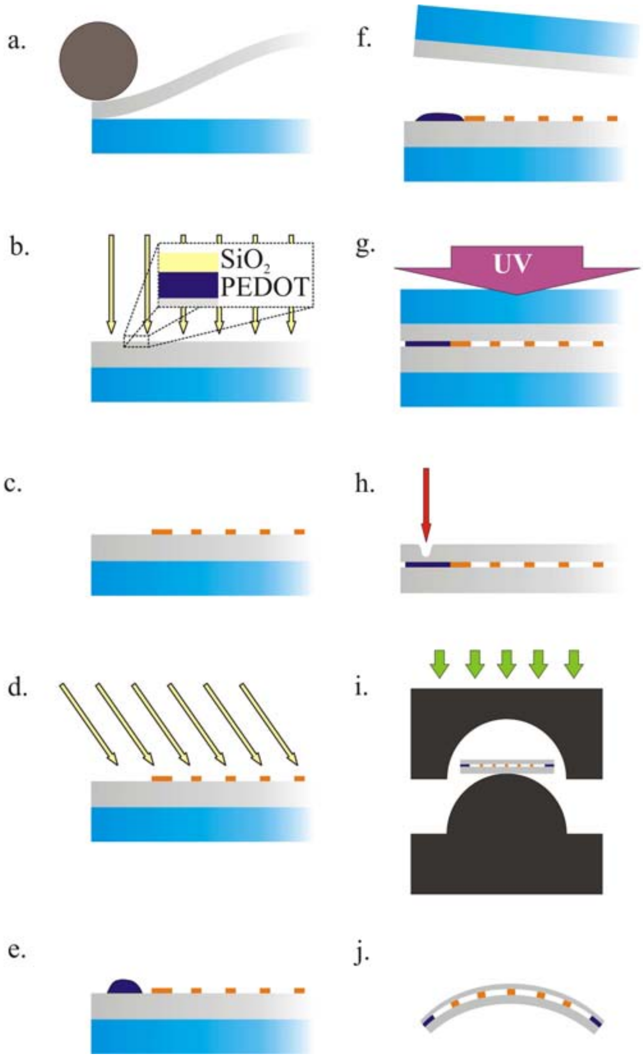


**Figure 4.** Process flow. a. the PET films are laminated onto a glass carrier b. PEDOT is spincoated on the PET films and the buffer layer is vertically evaporated on top c. the photolithographic layer is applied on the 75 µm PET film d. the alignment layer is obliquely evaporated e. the glue is deposited just next to the glue barrier f. a 50 µm PET film including the PEDOT, the buffer layer and the alignment layer is put on top g. the total stack is pressed together and illuminated with UV light h. after removal of the glass carriers, the lenses are cut out through the glue joint with a $CO_2$-laser and the entrance is reopened with an excimer laser i. the lenses are molded with a spherical aluminium mold j. after molding, a spherically conformed LC cell is formed, which can then be filled and sealed.

µm deep in the second film, thus reopening the LC cell entrance. The flat, cut-out lenses were then molded in an aluminum mold with a curvature radius of 7.8 mm. The molding process started with heating the whole mold to a temperature of 175°C, well above the glass transition temperature of PET (75°C). When the mold reached this temperature, the lenses were placed onto the bottom part of the mold and a soaking time of several minutes was applied. Afterwards, the upper part of the mold along with a weight of 1.2 kg was placed on top and the total ensemble was allowed to gently cool down until it was assured that the temperature of the mold was again well below the glass transition

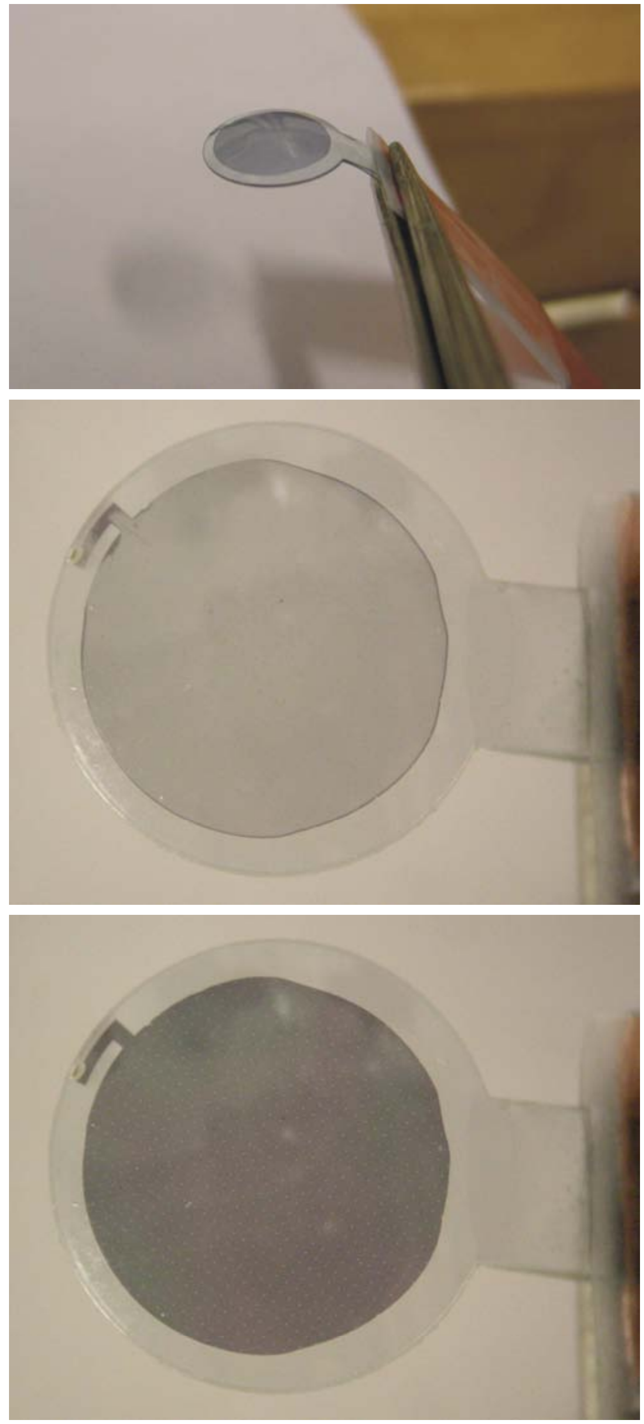

**Figure 5.** Up: The active LC cell is connected using a copper tape. Middle: Voltage off. Down: Voltage on.

temperature of PET before removing the lenses from the mold. After molding, active LC cells were filled with the guest-host liquid crystal mixture with a vacuum filling method and were sealed with the same glue used for the glue joint.

***Contrast Measurement:*** Contrast measurements were made by focusing the light of a xenon arc lamp onto a small spot on the LC cell and reading out the modulated light with an integrating sphere and an OceanOptics HR 2000+ spectrometer. The samples were driven with an AC voltage (f = 1 kHz, Vrms = 4V).

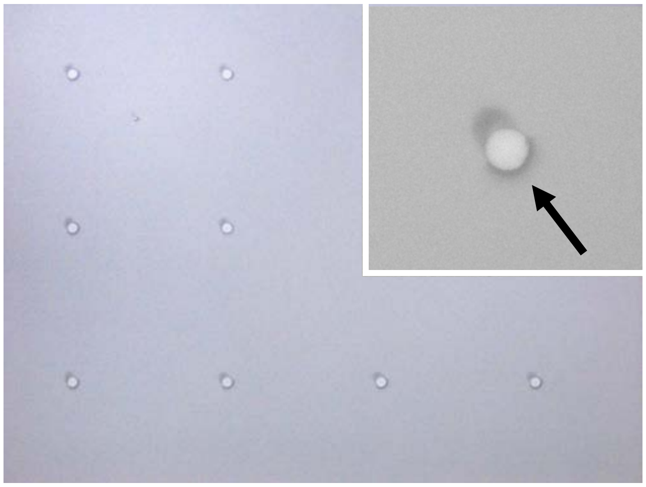

**Figure 6.** The matrix of vertical spacers after filling the cell with LC. Top Right: a close-up of such a spacer. The arrow represents the evaporation direction.

## 3. Results

***Active LC cell:*** When a voltage was applied to the LC cell, the electro-optic modulation could indeed be observed (see Figure 5), suggesting our approach and our fabrication process could indeed eventually lead to a contact lens display. A closer look at the spacers in the voltage off state (see Figure 6) reveals that the alignment in the surroundings of the spacers is, however, not perfect. When looking along the evaporation direction a shadow zone is present behind the spacers, as this area cannot be reached by the $SiO_2$-molecules and as a result, the LC molecules will not align homeotropically. The dark band observed at the front side of the spacers stems from the conflicting alignment directions imposed at the front side of the spacers and the bottom of the LC cell. The LC molecules will align perpendicular onto the spacer wall and a transient zone can be observed until the LC molecules are again homeotropically aligned with respect to the bottom of the LC cell. Nevertheless, the total effected area is small in comparison to the total area and should not hamper further development of the display

***Contrast Measurement:*** The contrast measurement (see Figure 7) reveals a peak contrast of about 1.4:1, which is rather low. However, the guest-host liquid crystal mixture was not yet optimized for this purpose. Further research should be performed on determining the parameters for a maximal modulating effect using this technological approach.

## 4. Impact

For the first time, a spherically conformed liquid crystal cell can actively modulate the incoming light, providing a low power alternative to micro-LEDs when aiming towards a contact lens display. Although the lens in its current shape has a rather simple functionality, patterning the PEDOT layer with even a low number of pixels could immediately lead to application such as contact lenses as tunable sunglasses or, when patterned in concentric circles, as an artificial iris, useful for aniridia patients.

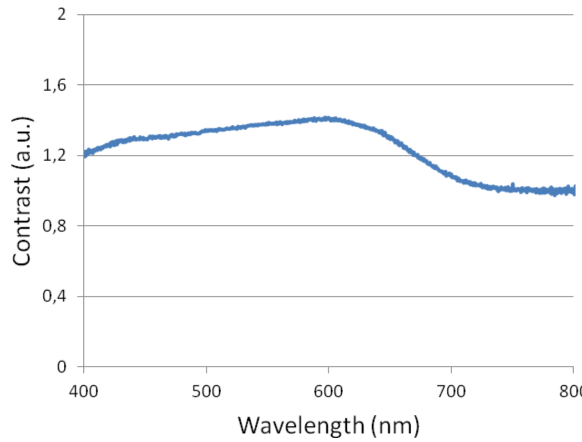


**Figure 7.** Contrast measurement of the LC cell.

## 5. Acknowledgements

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